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"Tools for Analysis and Visualization of Large Time-Varying CFD Data Sets"

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1 Results

During the four years of this grant (including the one year extension), we have explored many aspects of the visualization of large CFD datasets. These have included new direct volume rendering approaches, hierarchical methods, volume decimation, error metrics, parallelization, hardware texture mapping, and methods for analysing and comparing images.

First, we implemented an extremely general direct volume rendering approach that can be used to render rectilinear, curvilinear, or tetrahedral grids, including overlapping multiple zone grids, and time-varying grids. Opaque polygonal mesh surfaces can be included in the image. Different scalar data fields can be specified for rendering. The program, named `scremun`, runs in parallel on shared-memory multi-processor SGI platforms. It also runs as a single thread on Sun and other Unix platforms. Copies of this program were installed at NAS/NASA Ames for use on an experimental basis. Papers 5, 6, and 7 below describe this software.

Next, we developed techniques for associating the sample data with a k-d tree, a simple hierarchical data model to approximate samples in the regions covered by each node of the tree, and an error metric for the accuracy of the model. The hierarchical model guarantees data continuity when approximate rendering occurs at a single level of the tree. This hierarchy can be used in conjunction with the `scremun` direct volume renderer described in the previous paragraph to produce visual approximations of the dataset. Paper 3 below on this topic was presented at *IEEE Visualization '96*, in October 1996. Creation of the hierarchy requires solving the *point location problem* for 3D curvilinear grids; this problem was studied in Paper 9 below.

As an alternate approach to creating an explicit hierarchy, we have also developed automatic, error-based volume decimation methods. We explored this alternative approach as being more appropriate for very large data sets, where the extra expense of a tree may be unacceptable. This work was presented at *CGI '99* in June 1999 (Paper 1 below) and in earlier reports (Paper 2 and 8 below).

We also presented a paper (Paper 4 below) at the *ACM Symposium on Volume Visualization* in October 1996. This paper describes a new approach to direct volume rendering using hardware 3D textures and incorporates lighting effects. Volume rendering using hardware 3D textures is extremely fast, and machines capable of using this technique are becoming more moderately priced. While this technique, at present, is limited to use with regular grids, we are pursuing possible algorithms extending the approach to more general grid types.

We also explored a new method for determining the accuracy of approximate models based on the *light field* method described at ACM SIGGRAPH '96 (see Hanrahan and Levoy *Light Field Modeling* in that conference). In our initial implementation, we automatically image the volume from 32 approximately evenly distributed positions on the surface of an enclosing tessellated sphere. We then calculate differences between these images under different conditions of volume approximation or decimation. This provides a quantitative measure of the effects of approximation. The method is sketched in Paper 3 below.

We have created new tools for exploring the differences between images produced by various rendering methods. Images created by our software can be stored in the SGI RGB format. Our *ictools* software reads in pair of images and compares them using various metrics. The differences of the images using the RGB, HSV, and HSL color models can be calculated and shown. We can also calculate the auto-correlation function and the Fourier transform of the image and image differences. We are still exploring how these image differences compare in order to find useful metrics for quantifying the success of various visualization approaches.

2 List of Publications

From August 1995 to the present, we have produced the following publications.

1. Van Gelder, Allen, Vivek Verma, and Jane Wilhelms, 1999. ""Volume Decimation of Irregular Tetrahedral Grids," in *Computer Graphics International '99 Conference Proceedings.*

   This article describes approaches to decimating irregular tetrahedral grids using both density-based and mass-based error metrics.

2. Gibbs, Jonathan, Allen Van Gelder, Vivek Verma, and Jane Wilhelms, 1997. "Rapid Decimation for Direct Volume Rendering".

   This report describes our first approach based on automatic decimation of the volume. It is an extension of our scanline-based rendering method and can work on virtually any grid type. It gives some of the benefit of error-controlled approximate rendering that our k-d tree-based approach offers, but does not require the extra space of an explicit tree.

3. Wilhelms, Jane, Allen Van Gelder, Paul Tarantino, and Jonathan Gibbs, 1996. "Hierarchical and Parallelizable Direct Volume Rendering for Irregular and Multiple Grids", appeared in the *Proceedings of the IEEE Visualization '96 Conference*, October, 1996, pages 57–64.

   This article describes the general direct volume rendering approach that is the basis for our research into fast, approximate rendering of irregular grids.

4. Van Gelder, Allen, and Kwansik Kim, 1996. "Direct Volume Rendering with Shading", appeared in the *ACM Symposium on Volume Visualization*, October, 1996. See also UCSC technical report UCSC-CRL-96-16.

   This paper describes our new approach to direct volume rendering of regular grids using 3D hardware texture maps that incorporates lighting effects on surfaces.

5. Wilhelms, Jane, Paul Tarantino, and Allen Van Gelder, 1995. "A Scan-Line Algorithm for Volume Rendering of Multiple Curvilinear Grids", UCSC Technical Report UCSC-CRL-95-57.

   This technical report describes a method for direct volume rendering scalar data fields of irregular grids, including curvilinear and multi-grids, using a scan conversion approach.

6. Wilhelms, Jane, Paul Tarantino, and Allen Van Gelder, 1996. "Parallel Direct Volume Rendering for Multiple Overlapping Curvilinear Grids", to be presented as a 2-page abstract and poster session at the *15th International Conference Numerical Methods in Fluid Dynamics*, Monterey, California, June 1996.

   This two-page abstract briefly describes our visualization approach and its important for fluid dynamics visualization.

7. Tarantino, Paul, 1996. "Parallel Direct Volume Rendering for Multiple Overlapping Curvilinear Grids", Master's Thesis, Computer Science Department, University of California, Santa Cruz, 95064.

   This thesis describes in detail our new direct volume rendering approach, emphasizing the parts developed by the author.

8. Verma, Vivek, 1998. "Decimation for Volume Rendering of Tetrahedral Grids", Master's Thesis, Computer Science Department, University of California, Santa Cruz, 95064.

   This thesis develops the theory for decimating irregular tetrahedral grids based on local calculations of error metrics after a proposed vertex removal (decimation). The vertex that introduces the minimum error is selected for decimation, and error metrics are recalculated for neighboring vertices.

9. Colin, Cathi, 1996. "Point Location in 3D Curvilinear Grids", Ph.D. Thesis, Computer Science Department, University of California, Santa Cruz, 95064. Portions were presented as "Point Location in Curvilinear Grids", at the *6th International Symposium on Computational Fluid Dynamics*, December, 1995.

   This thesis develops a rigorous foundation for determining in which cell of a curvilinear grid a given point in 3D space lies. An algorithm is developed and evaluated in comparison with other point location algorithms.

3 Students Supported and Supervised

Graduate students partially supported by this project include: Jonathon Gibbs, Kwansik Kim, Thomas Raffill, Jianhwa Sun and Vivek Verma. Dr. Cathi Colin, a Ph.D. student supervised by P.I. Wilhelms, finished her Ph.D. in summer 1996 on a subject related to this project (point location in 3D curvilinear grids), but she was not funded by this grant.

Dissemination of Report

Copies of this report been sent to NAS/NASA Ames in Mountain View, Ca., and to the NASA Center for AeroSpace Information (CASI) in Maryland.